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# COCKPIT NOISE EXPOSURES ASSOCIATED WITH THE OPERATION OF FIXED- AND ROTARY-WING AIRCRAFT

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## FOREWORD

This research was accomplished in the Otolaryngology Branch under task No. 775508 from July 1966 to July 1969. The paper was submitted for publication on 22 January 1970.

This report has been reviewed and is approved.

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## ABSTRACT

Noise levels measured within the cockpits of 126 fixed- and rotary-wing aircraft have been tabulated and arranged into stereotyped sets of exposure envelopes. The noise data from which these envelopes were derived represent "typical" unprotected exposures encountered within 12 different categories of fixed- and rotary-wing aircraft during conditions of "normal cruise." Extreme or unique noise exposures have been deleted from the study.

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# COCKPIT NOISE EXPOSURES ASSOCIATED WITH THE OPERATION OF FIXED- AND ROTARY-WING AIRCRAFT

## I. INTRODUCTION

Modern aerospace vehicles possess the capability of delivering weapons that could essentially destroy the war-making capacity of a large and powerful country. Many of these same vehicles possess an equally effective ability to carry tons of hay and deliver it to isolated areas where cattle have been stranded by snow and ice. Other vehicles transport people thousands of miles each day. It is this potential diversity and multitask capability that has created the variety of aircraft types which now exist, and these significantly different forms of aerospace vehicles create noise exposures which are as diverse as are the types of aircraft (11).

Noise and vibration environments encountered within fixed- and rotary-wing aircraft have been progressively dictated by the types of power plants utilized in the various aircraft. In no small measure, the types of missions flown by an aircraft tend to further modify the noise exposures experienced by aircrew members. Many aircraft presently included within the military inventory of aerospace vehicles are capable of performing multifunctional missions. Because of the wide range of missions which a given vehicle may perform, individual noise exposures associated with a given mode of operation are difficult to define and evaluate (5, 10).

Noise exposures have significantly changed during the past quarter century. Until a few years ago, most rotary-wing aircraft were powered by reciprocating engines. Currently, many rotary-wing aircraft are being fitted with turboshaft engines (11). Even the turbojet engine which was prominent just a few years ago has been replaced by the turbofan and ducted-fan engine as the preferred power plant for fixed-wing aircraft. Vertical-takeoff-and-landing aircraft in many configurations are now being introduced. Most of these aircraft utilize new and revolutionary types of power plants and propulsive systems—ducted fans, ported fans, laminar flow jets, rotating pulse jets, and other forms of flight-propulsion systems (10, 16, 17). Because of the variety of aircraft types which now exist, it is no longer possible to specify a single noise-exposure envelope for all of them (3).

Unwarranted auditory and nonauditory problems occur when excessive noise and vibration levels are allowed to exist, especially when such exposures are encountered routinely by aircrew members (4, 7, 9, 10, 13, 14, 16-18). It is not the intent of this paper to recommend modifications to the currently acceptable acoustic levels; however, the author has attempted to present an overview of the various types of noise exposures and to classify them into characteristic noise-exposure profiles for major groups of fixed- and rotary-wing aircraft.

A variety of noise data measurements are plotted and depicted as composite, categorical noise-exposure envelopes. By use of this approach, a large bulk of data has been amassed in such a way that "generalities" (in the form of noise-exposure envelopes) can be expressed. An approach of this type necessitates compromises. Within the confines of this report, the author cannot specify the many conditions

which either directly or indirectly influence or bias the data—i.e., altitude, airspeed, powerplant operations, and many others. The data from which the different exposure envelopes were derived have been screened so that only "typical" noise environments are represented. Nontypical or unique noise data have been excluded.

Many intrinsic and extrinsic factors tend to modify the actual noise exposure encountered at a given location within an aircraft during various phases of flight (1, 2, 4, 5, 10). Although numerous nonspecified modifying factors are interposed in the data reported herein, the author feels that the approach used does allow certain general features of "typical" noise exposures to be identified, at least within certain limits.

## II. FIXED-WING AIRCRAFT

The following descriptions and illustrations depict the types of noise exposures which have been measured within the cockpits of various fixed-wing aircraft.

### Reciprocating engine aircraft

Of the 103 aircraft contained within the fixed-wing group, 50 of the vehicles are powered by reciprocating engines. In general, the two most significant sources of noise associated with the operation of reciprocating engine–powered aircraft are aeroelastic disturbances generated by propellers and engine exhaust (4-8, 10, 16). The noise produced by both of these components is most intense in the lower frequencies.

The most intense noise created by propeller disturbances is found in the area near the plane of rotation of the airscrew (10). In most multiengined aircraft, propeller-generated noise is most intense at positions just in front of the propeller plane. This means that stations occupied within a half to a full propeller diameter (distance) forward of the propeller plane usually contain the most intense exposures (6).

*Single reciprocating engine.* Noise measurements obtained within the cockpits of 9 different aircraft are shown in figure 1. As shown, the range of values determining the noise envelope encompasses the lowest to highest levels recorded for all eight octave bands. Note the relatively narrow range of the overall plottings from 110 to 117 dB. For the 9 exposures plotted, the peak noise levels were found in frequencies below 75 Hz in 3 cases; at 150 to 300 Hz in 1; and occupying the two lowest octaves (below 150 Hz) in 1. Therefore, the most intense noise elements are contained at frequencies below 300 Hz.

Individual levels which determined the lower range of the envelope for octaves above the frequency of 300 Hz were determined by exposures measured within two aircraft, the O-1E and the U-6A.

As one might expect, the size and number of blades in the propeller, the location of the engine exhaust (stacks), and the location and configuration of the cabin area in which the measurements were obtained had a modifying influence on the overall character of the noise (6). For instance, 3 of the aircraft were

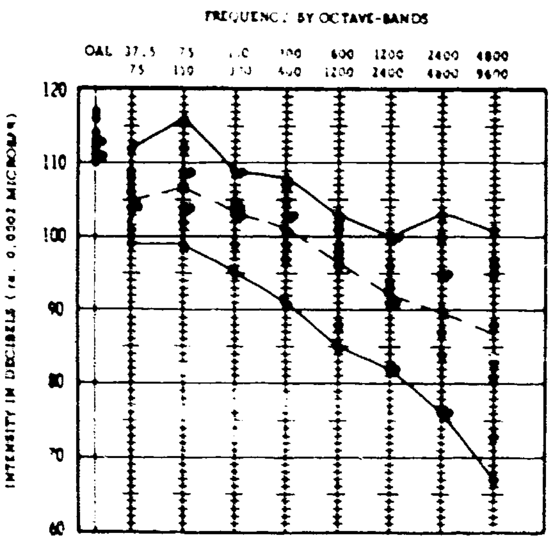


FIGURE 1

*Noise levels measured in the cockpits of 9 fixed-wing aircraft powered by single reciprocating engines.*

fitted with large engines rated at more than 1,500 hp., and 2 of these were fitted with large-diameter, 4-bladed propellers. The exposures measured within these 3 cockpits dominate the upper part of the envelope.

Analysis of the data plottings permits the following observations. The most noticeable variations in the width of the envelope occurred at frequencies above about 600 Hz. The type of noise measured within the cockpit area exhibits more intense acoustic energy in the higher frequencies when the aircraft is powered by large radial reciprocating engines that are mated to either 3- or 4-bladed propellers than when the aircraft is powered by a smaller reciprocating engine. In instances where a large radial engine is mated to 2-bladed propellers, the noise that emanates from the exhaust ports contains a noticeable amount of acoustic energy in the higher frequencies. Also, the heavier the gross weight of the aircraft the more equally distributed will be the acoustic energy present at frequencies below about 300 Hz (6, 10).

Contrary to what is generally accepted, the noise produced within single reciprocating engine aircraft does not "fall off" in the higher frequencies to a great extent (1). In fact, inspection of the individual data plots shown in figure 1 reveals that, when mean values are considered, there is only a 20-dB downward slope in the levels measured across the six octaves above 75 Hz. This amounts to a mean "roll off" of approximately 3.3 dB per octave. Although only mean values are given to demonstrate the general tendency, a clustering of exposures at values at and above the mean is apparent for frequencies contained within octaves between 150 and 2400 Hz.

*Twin reciprocating engines.* The envelope shown in figure 2 contains plottings of noise measurements obtained within 24 different aircraft powered by twin reciprocating engines. Of these, 12 sets of data represent noise levels encountered within cockpits which were located close to the propeller plane. Seven of the aircraft were fitted with engines of medium power (maximum power performance ratings that range from about 1200 to 1700 hp.) and 5 were fitted with individual engines rated at less than 450 hp. Of those included in the medium power range, 6 had 3-blade propellers and 1 was fitted with a 4-blade propeller. The peak noise levels measured for these 7 vehicles were exhibited at frequencies below 75 Hz in 5 aircraft, between 75 and 150 Hz in 1, and equally distributed in the two adjoining octaves below 150 Hz in 1. Of interest was the finding that the levels present in the octave 75 to 150 Hz were found to be most intense in 4 of the aircraft fitted with engines of less than 450 hp., and the remaining vehicle contained levels that were equally distributed within two octaves below 150 Hz.

Analysis of the peak noise levels measured within the cockpits of each of the remaining 12 aircraft (aircraft in which the cockpit was located at distances more forward of the propeller plane) rendered the following results: 8 aircraft were found to possess the most intense noise within the frequency range below 75 Hz and the remaining 4 contained peak levels in the single octave of 75 to 150 Hz.

Overall noise-level plottings for the 24 aircraft ranged from 102 to 120 dB. The shape

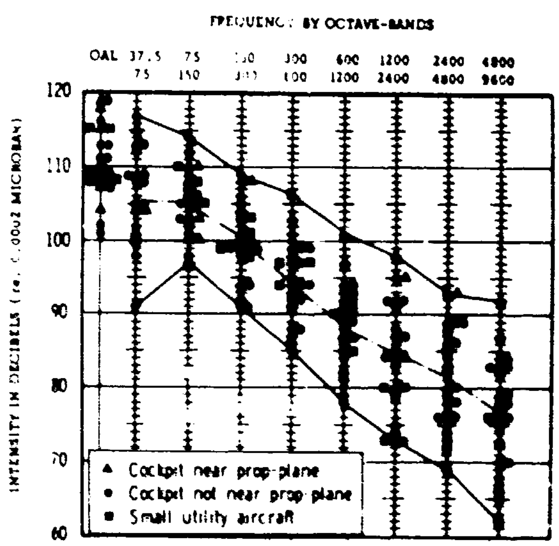


FIGURE 2

*Noise levels measured in the cockpits of 24 fixed-wing aircraft powered by two reciprocating engines.*

and levels which comprise the lower part of the envelope plotted for the various octaves closely resemble those previously shown in figure 1 (single reciprocating engine aircraft). Except for frequencies above 2400 Hz, the upper part of the envelope closely follows the general shape of the one shown in figure 1. One apparent difference noted between the plottings shown in figure 1 and figure 2 is the manner in which the individual data points depicted for dual-engine aircraft tend to cluster closer around the mean than those depicted for exposures measured within single-engine aircraft.

Analysis of the data revealed the following generalizations: First, the composition of the range of the envelope between low to high octave-band levels is relatively wide. For the eight octaves this range averaged 22.5 dB, but, if divided into two frequency ranges, the average range was 19 dB for the lower four octaves (below 600 Hz) and 26 dB for the upper four octaves (above 600 Hz). Second, except for the 91 dB plotting shown in the octave 37.5 to 75 Hz (plotted for an aircraft in which the peak level of 97 dB was contained in the adjoining higher octave 75 to 150 Hz), the average slope of the lower range of the noise envelope was about 5 dB per octave (moving from the lowest to the highest octave). Third, most of the 7 medium-powered aircraft in which the cockpit is located near the propeller plane produce noise which dominates the upper half of the total number of plottings shown within the envelope at octaves above 150 Hz. In fact, 5 out of the 7 plottings were distributed in octaves 150 to 300, 300 to 600, 1200 to 2400, and 2400 to 4800; and 4 each in the remaining two octaves 600 to 1200 and 4800 to 9600 Hz. This finding, plus careful study of the remaining individual 17 data sets, indicates that the presence of intense acoustic energy occurs most often within cockpits which are located fairly close to the propeller plane. Finally, the most intense noise components are found at frequencies below about 150 Hz. Over half (13) of the data sets contained peak noise levels within frequencies below 75 Hz; 9 possessed maximum levels in the octave 75 to 150 Hz, and 2 demonstrated maximum levels which coexist within the two lowest octaves (37.5 to 150 Hz).

*Four reciprocating engines.* Figure 3 contains 17 sets of noise measurements obtained in cockpits of aircraft powered by four reciprocating engines. The cockpits of 4 of the vehicles were located relatively close to the propeller plane, whereas the remainder were not. Of the 4 in which the cockpits were located near the propeller plane, 2 contained noise which peaked at frequencies below 75 Hz, 1 peaked at 75 to 150 Hz, and the other at 150 to 300 Hz. If plottings of the noise for these 4 aircraft are excluded from the envelope, the upper part of it shifts downward to that depicted by the interrupted line (also, the overall would then range from 95 to 109 dB). The envelope which results after exclusion of these 4 is probably more typical of exposure encountered within most contemporary four-engine aircraft. This alteration provides an envelope which has a low-to-high range per octave that is approximately equivalent throughout the frequencies. For instance, a mean of almost 17 dB per octave is found for all eight bands.

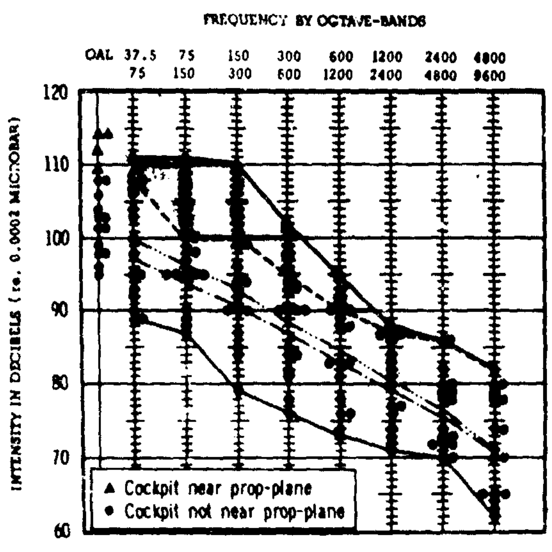


FIGURE 3

*Noise levels measured in the cockpits of 17 fixed-wing aircraft powered by four reciprocating engines.*

Apparently, the noise produced by four wing-mounted reciprocating engines is, in general, less intense throughout all frequency bands measured, especially within cockpits which are located some distance forward of the propeller plane. This observation is supported by the fact that when the noise levels measured in cockpits which were located near propellers are excluded from the plottings (as shown in figure 3), a rather significant decrease in the upper range of the envelope occurs which is most apparent at frequencies below about 1200 Hz. Furthermore, the relative significance of the type of noise encountered within the remaining 14 aircraft (after exclusion of the data composing the upper part of the envelope) is found to be much less.

**Turboprop-powered aircraft**

In many respects the noise measured within the cockpits of turboprop-powered aircraft closely resembles that contained within aircraft powered by reciprocating engines. The most prominent noise component is still created by propeller disturbances. Exhaust-generated noise, on the other hand, is not as noticeable within turboprop aircraft (6). In fact, the noise which emanates from the exhaust of a turboprop power plant is rarely audible at most occupied positions within the aircraft during normal flight.

In general, the propellers of turboprop aircraft rotate at higher blade-tip speeds than do the blades of reciprocating airscrews (5). This, coupled with the fact that most contemporary turbopropeller systems have four blades, causes the noise to have a somewhat different character than that generated by propellers of reciprocating power plants.

Two basic subgroups are described and illustrated for turbopropeller aircraft: aircraft fitted with two engines, and vehicles mated to four engines. The latter group is further classified according to commercial and military aircraft.

*Dual turboprop engine.* Figure 4 illustrates the envelope derived from plottings of the lowest to highest values measured within the cockpits of 5 different aircraft. The low-to-high range encompassed for each octave varied from 8 to 19 dB, with a computed mean value of slightly more than 13 dB for all eight octave bands. Of interest is the manner in which overall shape of the envelope slopes upward from the two lowest octaves to peak within the third octave, 150 to 300 Hz. This finding supports the observation that the noise produced by the propellers of turboprop-powered aircraft contains acoustic energy which peaks at a somewhat higher frequency than that observed within aircraft powered by reciprocating engines.

From the general shape of the envelope it appears that the level of the noise tends to increase between about 1200 and 4800 Hz (giving the impression of the existence of a second "hump"). It should be noted that the upper range of the envelope shown for frequencies above 1200 Hz (1200 through 9600 Hz) actually represents measurements obtained within the cockpit of only one aircraft, an OV-1A. Although the presence of such a hump is not entirely typical, it is apparent from the data plottings within three octaves that a plateau

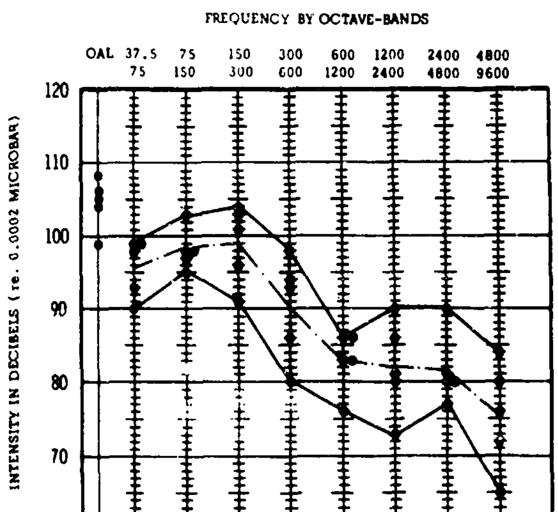


FIGURE 4

***Noise levels measured in the cockpits of 5 fixed-wing aircraft powered by two turboprop engines.***

does exist within the frequency range between about 600 and 4800 Hz. The presence of this plateau is even more obvious when one considers that the level of the noise measured in the octave 300 to 600 Hz drops by about 8 to 10 dB in the next adjoining octave, 600 to 1200 Hz.

For the 4 aircraft included, the most intense levels (the maximum, and all values 3.0 dB down from the maximum) were contained within 3 vehicles in the octaves 75 to 150 and 150 to 300 Hz, and the most intense noise component measured within 1 aircraft was encountered in the frequency range below 75 Hz. The one vehicle that contained a maximum distribution of noise in the frequency range below 75 Hz retained its next highest level in the 150 to 300 Hz band—an intensity only 4 dB less than the peak noted below 75 Hz.

Analysis of the total number of data points for octaves within which the levels were within 3 dB of the maximum (and including the peak values) reveals that, for the data plotted for twin reciprocating powered aircraft, 54.8% of such maximum and near-maximum levels occurred at frequencies below 75 Hz, 41.9% at 75 to 150 Hz, and 3.2% at 150 to 300 Hz. In contrast, data obtained from twin-powered turboprop aircraft indicated that only 16.7% occurred at frequencies below 75 Hz, 33.3% at 75 to 150 Hz, and 50.0% at 150 to 300 Hz. These findings support the contention that the noise produced within the cockpit of twin-powered turboprop aircraft contains a form of intense acoustic energy that is somewhat higher in frequency than is noted within aircraft powered by two reciprocating engines.

*Four turboprop engines.* Figure 5 contains a combination of two envelopes, one for military versions of four-engine aircraft and another for commercial versions. Naturally, the interiors of vehicles employed solely as commercial carriers contain more acoustic materials than do military vehicles. Of necessity, military aircraft cannot be as heavily treated as commercial counterparts, primarily because of weight and overall performance limitations (15, 17, 18).

Noise levels measured within the cockpits of 8 military aircraft are contained within the upper envelope shown in figure 5, and levels measured within 4 commercial vehicles are encompassed within the limits of the lower envelope. Note that in the upper range of the envelope, depicting military turboprop aircraft, the levels are somewhat higher in the two lowest octaves than in the envelope shown for aircraft fitted with two turboprop engines (fig. 4). Furthermore, the range shown for the overall measurements is different: for aircraft fitted with four engines, the range of overall values extends from 99 to 114 dB for military versions, and from 90 to 100 dB for commercial turboprop aircraft. When compared with levels derived from measurements completed within cockpits of aircraft powered by four reciprocating engines (excluding the 4 reciprocating aircraft with cockpits located very near the inboard propeller plane), the levels reported in military turboprop aircraft render mean values that exceed mean values obtained for the reciprocating aircraft at all octaves. In fact, comparison of the mean

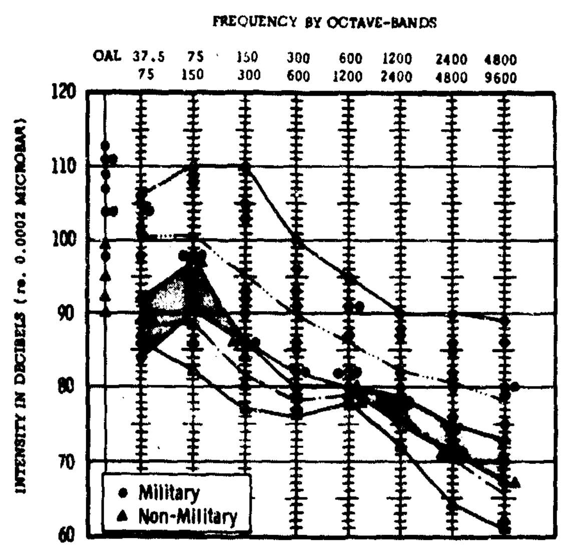


FIGURE 5

*Noise levels measured in the cockpits of 12 fixed-wing aircraft powered by four turboprop engines. The upper envelope shows the range of levels measured in 8 military turbopropeller aircraft and the lower envelope shows the range of levels measured in 4 commercial turbopropeller aircraft.*

levels computed for turboprop aircraft reveals that the mean levels exceed those computed for reciprocating aircraft by 5.5 dB for the overall, 3.4 dB at 37.5 to 75 Hz, 7.2 dB at 75 to 150 Hz, 5.3 dB at 150 to 300 Hz, 2.4 dB at 300 to 600 Hz, 3.3 dB at 600 to 1200 Hz, 3.1 dB at 1200 to 2400 Hz, 4.5 dB at 2400 to 4800 Hz, and 8.1 dB at 4800 to 9600 Hz. If the values by which the levels recorded in turboprop aircraft exceed reciprocating aircraft are averaged throughout the eight octaves, the average increase is 4.7 dB, which, interestingly enough, closely agrees with the mean increase noted between the overall levels.

In general, the foregoing emphasizes that the basic noise levels encountered within cockpits of turboprop aircraft are somewhat more intense than those found within aircraft powered by reciprocating engines, especially within the frequency range encompassed by the second and third octaves (7.2 and 5.3 dB, respectively) and the highest two octaves (4.5 and 8.1 dB, respectively).

If mean values for military turboprop aircraft are compared with those computed for commercial turboprops, the levels throughout all bands (and the overall) are found to be greater for the military than for the civilian vehicles (fig. 5).

These findings clearly emphasize that most military aircraft powered by four turboprop engines contain noise which is significantly higher than that associated with the operation of aircraft powered by either reciprocating engines or commercial versions of turbo-propeller-powered aircraft.

**Turbojet and turbofan engines**

Most modern high-performance fixed-wing aircraft are powered by either jet or fan-jet engines (11). The types of noise exposures encountered within the cockpits of most of these aircraft differ considerably from those previously described.

The cockpit of almost all jet-powered aircraft is located forward of the engines and the rather intense noise which is commonly associated with the jet exhaust stream disturbances does not dominate the unprotected exposures which are encountered at stations forward of the engines, especially during conditions of normal flight (6).

Several aircraft-to-engine mating configurations now exist. These differences, coupled with different performance and operational characteristics, result in different noise exposures. For simplicity, the following groups of aircraft engine matings were used to evolve the noise envelopes contained within this section of the report: (1) aircraft in which the engine or engines are installed internally or semi-internally (integral fittings), and (2) aircraft with engines fitted externally.

The primary sources of noise found within the cockpits of jet-propelled aircraft include aerodynamic disturbances and other forms of aeroelastic disturbances which result from the operation of different environmental control systems (1, 4, 8, 12, 18). Noise associated with aerodynamic disturbances results when outer sections of the fuselage, canopy, or windshield encounter aerodynamic loadings which are imposed on the aircraft by the surrounding atmosphere through which the vehicle travels.

Although several of the aircraft included within this section possess supersonic speed capability, only noise levels measured within cockpits during normal subsonic maneuvers are considered.

*Internal and semi-internal fitted turbojet engines.* Aircraft contained within this section include attack- (A), fighter- (F), and trainer (T) types. Single and tandem, or side-by-side, seating arrangements and single- and dual-engine matings are represented.

The envelope shown in figure 6 is composed of noise measurements which were obtained within 20 different types and models of aircraft with internal or semi-internal fitted single or dual engines. Note that the range of overall measurements extends from a low of 96 dB to a high of 109 dB, a total range of

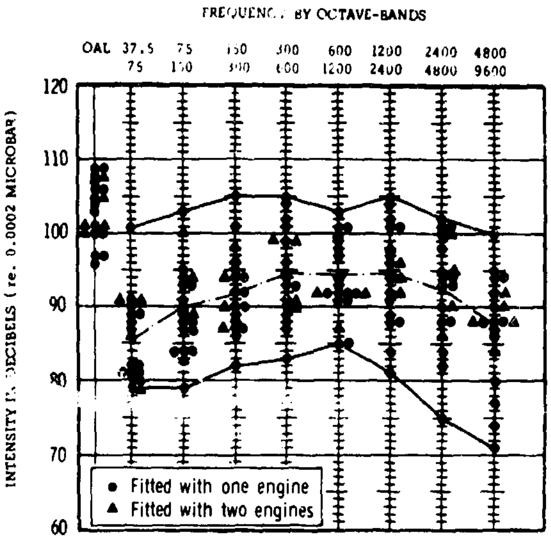


FIGURE 6

*Noise levels measured in the cockpits of 20 fixed-wing aircraft powered by single or dual internal or semi-internal fitted turbojet engines.*

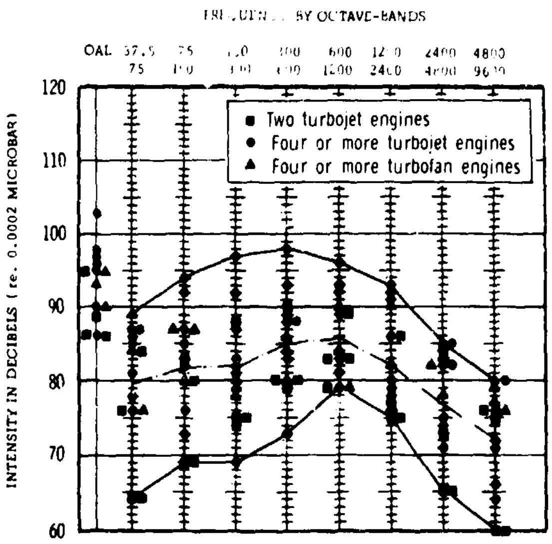


FIGURE 7

*Noise levels measured in the cockpits of 14 fixed-wing aircraft powered by externally wing-mounted turbojet or turbofan engines.*

only 13 dB. By contrast, the relatively narrow range represented for the overall levels is not retained throughout the eight octaves. The average range obtained for the low-to-high values for all eight octaves is 23.9 dB.

The distribution of the noise levels measured in the eight octaves in these aircraft is clearly evident. Findings obtained from computing the octaves which contain levels within 3 dB of the maximum at the eight octaves reveal that distributed within the frequency range above 300 Hz is 82.3% of the most intense levels encountered within the cockpits of the various aircraft included in this section. Of particular interest is the finding that 66.6% of these maximum, and near-maximum (within 3 dB), levels occur within three adjoining octaves—from 300 through 2400 Hz.

*Wing-mounted turbojet and turbofan engines.* The envelope shown in figure 7 represents noise measurements obtained within the cockpits of 14 different aircraft. Separate data points are shown for (1) aircraft fitted with four or more turbojet engines, (2) those with four or more turbofan engines, and (3) those fitted with two engines. In all instances, the power plants were installed either within the wings or within pods and attached by pylons to the under surfaces of the wings. Scrutiny of the data plottings which compose the envelope depicted in figure 7 shows that the upper part of the envelope that crosses the frequency range between 75 and 2400 Hz primarily contains noise levels obtained within multiturbojet engine–powered aircraft. In general, the lower section of the envelope is dominated by levels measured in aircraft powered by two engines, especially those levels shown for octaves below 150 Hz and above 1200 Hz.

Inclusion of the maximum, and levels within 3 dB of the maximum, reveals that 61.3% of the most intense levels occurred at frequencies above 300 Hz. In fact, 48.4% of the maximum and near-maximum levels are contained within two adjoining octaves; namely, 300 Hz through 1200 Hz.

The average spread of low-to-high values shown for all eight octaves is 22.3 dB. Note that the width of the envelope is wider for

octaves below 600 Hz and slightly narrower for those above 600 Hz. This range varies from a mean value of 25.7 dB for levels recorded in the four octaves below 600 Hz to 18.7 dB for those above 600 Hz.

The mean intensity values obtained for the overall levels for 14 aircraft fitted with externally mounted engines is 10.4 dB less than the mean computed for the 20 internal and semi-internal mated engines (fig. 6). Also, the differences noted for means computed for data points shown at all eight octaves are less for multiengine aircraft than for vehicles with internal or semi-internal fitted engines. The intensity levels encountered within the cockpits of internal and semi-internal mated power plants averaged 10.5 dB more for all eight octaves. More specifically, the means for the eight octaves were found to be more intense within internally or semi-internally mounted engine vehicles by values of 5.5 dB at 37.5 to 75 Hz, 8.1 dB at 75 to 150 Hz, 10.4 dB at 150 to 300 Hz, 9.4 dB at 300 to 600 Hz, 8.7 dB at 600 to 1200 Hz, 11.8 dB at 1200 to 2400 Hz, 14.8 dB at 2400 to 4800 Hz, and 15.0 dB at 4800 to 9600 Hz.

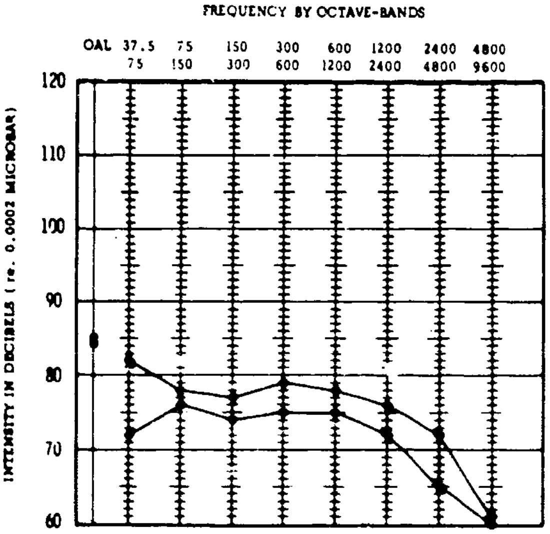


FIGURE 8

*Noise levels measured in the cockpits of 2 fixed-wing aircraft powered by externally tail-mounted turbojet engines.*

*Tail-mounted turbojet engines.* Figure 8 shows noise measurements obtained within the cockpits of 2 aircraft fitted with turbojet engines that are contained in nacelle pods and attached by short pylons to the far aft section of the main fuselage. This configuration of engine-to-aircraft mating has received a fair degree of acceptance and, as evidenced by the levels shown in figure 8, the noise present within the cockpits of such aircraft during conditions of normal cruise is relatively low.

The noise levels encountered within these 2 vehicles is dictated by different forms of aerodynamic disturbances. As airspeed increases, the level of the noise increases (8). This type of noise is most apparent within the frequency range between about 150 through 2400 Hz. Even the upper element of the envelope shown in figure 8 represents relatively low levels of noise exposure.

## III. ROTARY-WING AIRCRAFT

The development and growth of rotary-wing aircraft has been phenomenal (11). Where previously most of these vehicles were powered by reciprocating engines, now most receive power from turboshaft power plants. Because of the variety of design profiles which now exist, this section considers two basic groups—aircraft fitted with a single main rotor (and a single antitorque rotor) and those fitted with dual main rotors (tandem, or side-by-side intermeshing type). Each of these 2 categories is subgrouped according to the type of power plant used to supply shaft power to the rotors.

The acoustic disturbances created by main rotors closely resemble those produced by conventional propellers (2). Of course, rotors do not rotate at shaft speeds equivalent to those of propellers but, because rotors have larger diameters, even at low speeds the blade tips achieve velocities which approach high blade-tip speeds of conventional smaller diameter (but higher speed) propellers (2, 4, 10, 15, 16). Therefore, rotors do produce rather significant noise during most phases of airborne operation.

In general, rotors generate acoustic disturbances which are found to be most intense within the lower frequency range, usually below 600 Hz (10).

Transmissions and gear-distribution systems produce noise that is of major significance when such units are located in near proximity to occupied spaces within the vehicle (6). Therefore, these sources of noise are most evident in helicopters in which the cockpit is located near such units. The noise produced by these systems is rich in narrow-band noise components, usually distributed within frequencies above 300 Hz.

The noise produced by different types of power plants fitted in helicopters differs considerably from one aircraft to another. In general, at least in the cockpit area, the noise produced by reciprocating engines is found to be more intense than that of turboshaft-engine vehicles (10, 16).

Gas turbine, or turboshaft, power plants do not produce as much noise as reciprocating engines, especially within the area of the cockpit. In general, turboshaft engines in a helicopter are installed at locations which are further aft of the cockpit than in vehicles powered by reciprocating engines. This feature, coupled with the fact that noise produced by the exhaust of turboshaft engines is less intense than that produced by reciprocating engines, results in less noticeable engine-generated noise within the cockpit. Also, modes of mechanically induced vibrations produced by turboshaft engines are less intense.

**Single main rotor aircraft**

Contained within this section are 2 categories of single rotor aircraft: one for vehicles fitted with reciprocating engines; the other for helicopters powered by turboshaft engines. Of the 17 vehicles included within the single rotor group, 6 were powered by reciprocating engines and 11 by turboshaft engines. The data from which the envelopes for the noise in rotary-wing aircraft were determined were taken from measurements obtained within the cockpit of each aircraft during conditions of normal cruise.

*Reciprocating engine, single rotor aircraft.* The composite noise envelope shown in figure 9 was derived from plotting noise levels measured within the cockpits of 6 types of single rotor vehicles powered by reciprocating engines. Two of the vehicles were powered by radial reciprocating engines which were mounted just below and forward of the cockpit, 3 were fitted with in-line reciprocating engines which were installed just aft of the cockpit, and 1 vehicle had two radial engines which were contained in pods and attached to the sides of the fuselage at a position aft of the cockpit. The number of blades which composed the main rotor of the 6 rotorcraft contained in this series varied from 2 to 5.

The average range of sound pressure, computed from the lowest to highest levels recorded at each octave, was 8.6 dB—a relatively narrow range when one considers that the 6 aircraft included in this group represent different type engines (in-line versus radial),

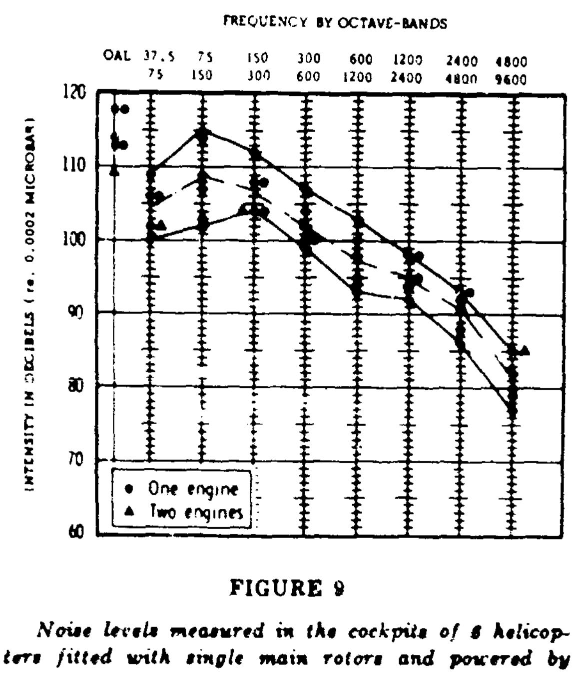


**FIGURE 9**

*Noise levels measured in the cockpits of 6 helicopters fitted with single main rotors and powered by reciprocating engines.*

different rotor systems, and different engine-to-aircraft matings. The most noticeable deviations found in the width of the envelope occurred within two octaves; the range for the 75 to 150 Hz octave was 13 dB, and for the 600 to 1200 Hz octave the range was 10 dB. The range of levels measured from low to high for the remaining octaves is within 2 dB of the computed mean for all eight octaves.

As for the frequency distribution of the maximum levels recorded for each octave, 72.8% of all recorded maximum and near-maximum levels are contained within the frequency range from 75 through 300 Hz. In fact, 91.0% of the maximum and near-maximum levels were recorded at frequencies below 300 Hz (in the three lowest octaves).

*Turboshaft engine, single rotor aircraft.* Figure 10 depicts a composite noise envelope derived from plottings of data obtained within the cockpits of 11 single-rotor helicopters powered by turboshaft engines. Although the overall shape of the envelope is similar to that for reciprocating engine-powered, single-rotor vehicles shown in figure 9, the width of the envelope is considerably different. Whereas the average width for the eight octaves of the envelope shown in figure 9 is 8.6 dB, the envelope width shown in figure 10 is 22.2 dB. Also, it is the shape of the upper part of the envelope for turboshaft-powered vehicles which most resembles that shown for reciprocating engine helicopters.

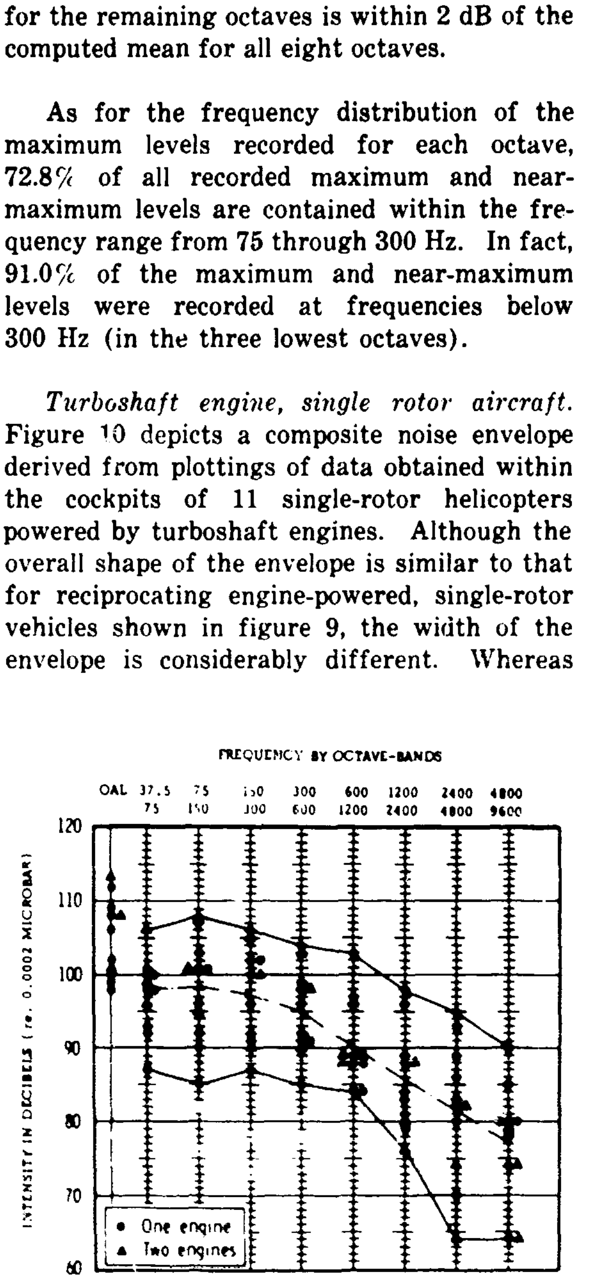


FIGURE 10

*Noise levels measured in the cockpits of 11 helicopters fitted with single main rotors and powered by turboshaft engines.*

Of the maximum and near-maximum levels recorded for the various octaves, 65.2% occurred at frequencies below 150 Hz (the two lowest octave bands). If the number recorded for the third band, 150 to 300 Hz, is included, the percentage of occurrences found at frequencies below 300 Hz increases to 86.9%. Therefore, the most intense noise components recorded within the cockpits of turboshaft-powered single-rotor helicopters are most prevalent at frequencies below 300 Hz, a finding that parallels that derived from the study of the single-rotor vehicles powered by reciprocating engines.

The rather wide range shown in figure 10 for the low-to-high values recorded at each octave is due to numerous factors. It is beyond the scope of this report to discuss the different sources of noise responsible for this variance. In any event, one fact is obvious: The types of exposure encountered within different helicopters fitted with single main rotors and powered by turboshaft engines vary considerably from one vehicle to another—to a greater extent than was indicated by similar data obtained from helicopters powered by reciprocating engines.

**Dual main rotor aircraft**

This section describes and illustrates noise levels measured within helicopters fitted with two main rotors and powered by reciprocating or turboshaft power plants. Three of the 6 aircraft fitted with two main rotors were powered by reciprocating engines and 3 were powered by turboshaft power plants. To conserve space, the two envelopes are shown in a single figure (fig. 11). Two basic types of dual-rotor configurations are represented in both subgroups: tandem nonintermeshing rotors, and side-by-side intermeshing rotors.

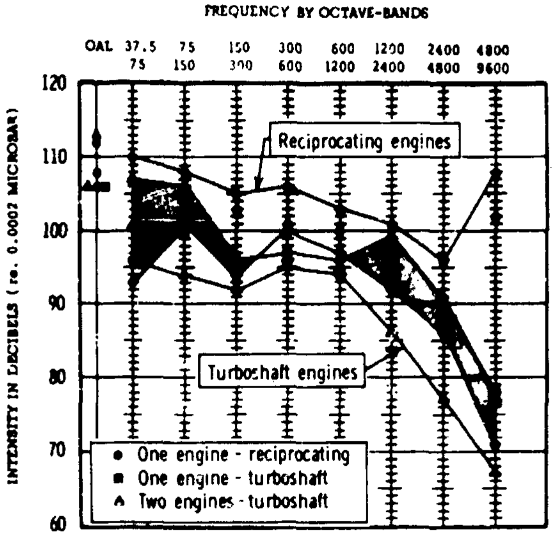


FIGURE 11

*Noise levels measured in the cockpits of 6 helicopters fitted with dual main rotors and powered by reciprocating- or turboshaft engines.*

*Reciprocating engine, dual rotor aircraft.* Noise levels measured within the cockpit area of 3 aircraft of this type are shown in figure 11 (envelope designated "reciprocating"). The range and shape of the envelope which evolved from the plottings is somewhat different from that shown for turboshaft vehicles. In general, levels recorded within vehicles powered by reciprocating engines are somewhat more intense than those encountered within vehicles powered by turboshaft engines.

In helicopters powered by reciprocating engines, the occurrence of maximum and near-maximum levels was found to occupy a rather wide spread of intensities throughout the frequency bands. For instance, recordings of levels within 3 dB of the maximum (and including maximums) were found to exist at all octaves except one, 2400 to 4800 Hz. A brief glance at the plottings contained within the envelope shown for reciprocating engine vehicles reveals the existence of fairly intense noise within the higher frequencies. The upper two data points plotted in the octave 4800 to 9600 Hz were recorded within aircraft in which elements of narrow-band noise were generated by transmission and gear reduction units which were located near the cockpits. The lowest point recorded for this same octave (4800 to 9600 Hz) was measured within a cockpit in which the presence of transmission noise was evident, but it was distributed mainly in two lower frequency octaves; namely, 300 through 1200 Hz. Although the wide range of values shown for 4800 to 9600 Hz plottings is unique, it does serve to demonstrate the existence of differences in exposures which may be encountered within the cockpits of different rotary-wing aircraft.

*Turboshaft engine, dual rotor aircraft.* Noise exposures measured within 3 turboshaft-powered dual-rotor vehicles are depicted in the second envelope shown in figure 11 (envelope labeled "turboshaft"). Of the 3 vehicles in this group, 1 was fitted with dual intermeshing rotors and the other 2 were fitted with dual tandem rotors.

Analysis of the values for the low-to-high plottings shown for the eight octaves reveals that the average width of the envelope throughout the eight octaves is 8.7 dB. It is interesting to note comparability of the levels encountered within 3 different types of vehicles within the three octaves between 150 and 1200 Hz.

As evidenced by the two envelopes shown in figure 11, noise produced within twin rotorcraft that are powered by turboshaft engines is less intense than that measured within vehicles powered by reciprocating engines, at least during conditions of normal cruise.

One fact is obvious: regardless of the type of power plant employed, considerably different exposures may be encountered at frequencies above 1200 Hz depending on the particular vehicle in which the measurements are obtained. The presence of this variable is dominated by noise elements which are associated with the main and secondary transmission, gear reduction units, and shaft distribution systems.

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13. ABSTRACT

Noise levels measured within the cockpits of 126 fixed- and rotary-wing aircraft have been tabulated and arranged into stereotyped sets of exposure envelopes. The noise data from which these envelopes were derived represent "typical" unprotected exposures encountered within 12 different categories of fixed- and rotary-wing aircraft during conditions of "normal cruise." Extreme or unique noise exposures have been deleted from the study.

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